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# Trophic Ecology of Native and Introduced Catfishes in the Tidal James River, Virginia

Louis Fairfax Chandler  
chandlerlf@hotmail.com

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College of Humanities and Sciences  
Virginia Commonwealth University


This is to certify that the thesis prepared by Louis Fairfax Chandler, entitled "Trophic Ecology of Native and Introduced Catfishes in the James River, Virginia" has been approved by his committee as satisfactory completion of the thesis requirement for the degree of Master of Science.



Gregory C. Garman, Ph.D.  
Director of Thesis



Leonard A. Smock, Ph.D.  
Chairman, Department of Biology  
Committee Member




Donald R. Young, Ph.D.  
Director, Graduate Program in Biology  
Committee Member



Steven R. Rein, Ph.D.  
Committee Member



Stephen D. Gottfredson, Ph.D.  
Dean, College of Humanities and Sciences



Jack L. Haar, Ph.D.  
Dean, School of Graduate Studies

May 7, 1998  
Date

**Trophic Ecology of Native and Introduced  
Catfishes in the Tidal James River, Virginia**

**A thesis submitted in partial fulfillment of the requirements for the degree  
of Master of Science at Virginia Commonwealth University, Richmond**

**By**

**Louis Fairfax Chandler  
Bachelor of Arts in Environmental Studies, Biology Minor  
Randolph-Macon College, 1995**

**Major Professor: Dr. Greg C. Garman  
Department of Biology / Center for Environmental Studies**

**Virginia Commonwealth University  
Richmond, Virginia  
April, 1998**

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## Abstract

### Trophic Ecology of Native and Introduced Catfishes in the Tidal James River, Virginia

By Louis Fairfax Chandler

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science at Virginia Commonwealth University, Richmond.

Virginia Commonwealth University, Richmond, Virginia, 1998

Major Professor: Dr. Greg C. Garman, Department of Biology / Center for Environmental Studies

Species introductions have been linked to the decline of native taxa, and in many cases have resulted in the elimination of native species in both terrestrial and aquatic systems throughout the United States. In aquatic systems, a particular threat is the introduction of large piscivorous fish that may alter the native fish community structure. For example, introductions of large ictalurids such as blue catfish, (*Ictalurus furcatus*), and flathead catfish, (*Pylodictus olivaris*), into coastal Virginia rivers, including the James River twenty years ago have resulted in the establishment of these large, predatory fishes.

This study described the trophic ecology of four ictalurid catfishes in the tidal James River, Virginia including the native white catfish (*Ameiurus catus*), the possibly introduced channel catfish (*Ictalurus punctatus*), and the recently introduced blue catfish and flathead catfish. The objectives of this study were to determine the trophic ecology of these four catfishes in a coastal Virginia river, and to assess the potential predatory effects of large, recently introduced

piscivorous ictalurids on the native fish assemblage, and especially anadromous clupeid fishes.

A stratified sample of 4,164 catfish was taken throughout the tidal freshwater reach of the James River during the summer and fall, 1996 and spring, 1997. Stomach content analysis revealed that blue catfish and flathead catfish are highly piscivorous, feeding on several families of native fishes. Flathead catfish consumed over 90% (frequency of occurrence) fish prey in most predator size classes and began consuming more fish prey at smaller sizes than blue catfish. Blue catfish shifted to a mostly piscivorous diet at predator lengths > 500 mm. Both blue catfish and flathead catfish consumed adult anadromous clupeids. The greatest numeric proportion (0.41) of anadromous clupeids consumed were juvenile *Alosa spp.* (<100 mm) taken by small blue catfish (<500 mm) during the fall sampling season. Piscivory was much less extensive in channel catfish and white catfish (less than 10% frequency of occurrence for all predator size classes). There is evidence of negative consequences to native fishes associated with the introductions of blue catfish and flathead catfish into Atlantic slope rivers. These consequences may conflict with current restoration efforts for native fishes such as the anadromous clupeids in these rivers.

## Introduction

Introduced species in aquatic systems may affect native species as a consequence of predation, competition, habitat modification, transfer of new parasites, and hybridization (Moyle et al. 1985, Crivelli 1995). Although introductions of aquatic species may not be detrimental (Holomuzki and Stevenson 1992, Mills et al. 1996), irreversible ecological consequences have been documented following establishment of nonindigenous taxa in aquatic systems (Laurenson and Holcutt 1985, Bunkley-Williams et al. 1994, Coates and Ulaiwi 1995, Abrams 1996).

Most intentional fish introductions were intended to improve sport or commercial fishing (Courtenay and Robins 1989). However, a substantial proportion of these introductions have been associated with the reduction or extirpation of native fish populations (Taylor et al. 1984). The most detrimental introductions have involved apex predators (i.e., piscivores) that eliminated native species by predation (Courtenay and Moyle 1992, Moyle and Light 1996, McPeck 1998). The effects of predation by nonindigenous fishes have been most severe where no comparable native predators have existed historically (Garman and Nielsen 1982). For example, the flathead catfish (*Pylodictus olivaris*) was introduced into the Cape Fear River, North Carolina and was linked to the decline of several native fishes (Guier 1984). The brown trout (*Salmo trutta*) displaced native salmonids where introduced throughout the U.S. (Waters 1983) and has further reduced other native fishes such as the torrent sucker

(*Thoburnia rathoea*) in a Virginia Piedmont stream (Garman and Nielsen 1982). Introduced Nile perch (*Lates niloticus*) in Lake Victoria, Africa have been associated with the extirpation of over 200 native fishes (Okach and Dadzie 1988, Oguto-Ohwayo 1990, Courtenay and Moyle 1992, Goldschmidt et al. 1993). Direct predation and decline in native fish abundance may not be the only impact by nonindigenous piscivores in aquatic systems. Effects of nonindigenous piscivores may also cascade through different trophic levels, and may even alter primary production in a system as a result of top-down effects (Carpenter and Kitchell 1988, Bechara et al. 1992).

Beginning with the establishment of the common carp (*Cyprinus carpio*) in New York during the early nineteenth century (Cole 1905, Moyle 1997), over 30% of current fish fauna in the United States has been introduced (Moyle et al. 1985, Poe et al. 1991, Courtenay and Moyle 1992). Several of these introductions occurred in ecosystems previously disturbed by human activity, and lead to the rapid extirpation of already threatened fauna (Moyle et al. 1986). For example, in the Little Colorado River, Arizona, five introduced fishes were found to frequently consume the endangered humpback chub (*Gila cypha*) and other native fishes (Marsh and Douglas 1997).

Impacts of nonindigenous fishes may compromise restoration efforts to native fishes in the United States. The reestablishment effort to the razorback sucker (*Xyrauchen texanus*) in the Gila River, Arizona has been unsuccessful due to predation by nonindigenous channel catfish (*Ictalurus punctatus*) and

flathead catfish (Marsh and Brooks 1989). The declining anadromous salmonid fishery of the Pacific Northwest and restoration efforts to these fishes is stressed further by the top-down effects of introduced piscivores such as walleye (*Stizostedion vitreum*) and channel catfish (Poe et al. 1991).

On the Atlantic coast, predation by both native and introduced fishes on hatchery reared American shad may compromise restoration efforts for anadromous clupeids in the Chesapeake Bay region (Johnson and Dropkin 1992). Two large and piscivorous ictalurids, the blue catfish (*I. furcatus*) and the flathead catfish, have been introduced in several Atlantic slope rivers of the eastern United States. In the mid 1970's, blue catfish and flathead catfish were introduced into the James River, Virginia from the Mississippi drainage (Jenkins and Burkhead 1994). Both species have become widely distributed and abundant within Virginia coastal rivers in recent years. Blue catfish is the largest North American ictalurid, and both blue catfish and flathead catfish may exceed 45 kg (Pelzman 1971, Jenkins and Burkhead 1994). The Virginia state record blue catfish weighed over 29 kg and was taken from the James River in 1994. Blue catfish and flathead catfish are highly piscivorous (Brown and Dendy 1961, Perry 1969, Turner and Summerfelt 1970, Guier 1984) and exhibit an ontogenetic diet shift from mostly invertebrates in smaller size classes while shifting to piscivory in larger size classes (Brown and Dendy 1961, Perry 1969, Turner and Summerfelt 1970, Guier 1984). Two other large ictalurids found in the James River, Virginia are the channel catfish and the white catfish (*Ameiurus*

*catus*). The white catfish is the only native catfish species to the James River examined in this study and channel catfish were probably introduced to Atlantic slope rivers in the late nineteenth century (Jenkins and Burkhead 1994). Channel catfish and white catfish are omnivorous, eating mostly invertebrates, plant material, and small amounts of fish prey in southern reservoirs and rivers (Stevens 1959, Ware 1966, Davis 1979).

Little is published regarding the trophic ecology of ictalurids in Atlantic coastal rivers, or of the potential interactions among native and nonindigenous fishes (Sauls et al. 1998). Historically, no other resident, piscivorous fishes approached the size and abundance of blue catfish and flathead catfish currently inhabiting the James River. In the James River, the once commercially important anadromous clupeids, the American shad (*Alosa sapidissima*) and the blueback herring (*A. aestivalis*), have rapidly declined coincidentally during the same two decades as blue catfish and flathead catfish have been introduced and become well established.

Large numbers of ecologically and commercially important anadromous fishes have historically utilized tidal rivers of the Atlantic Slope as spawning and nursery habitat (Mansueti and Kolb 1953, Garman 1992, Garman and Nielsen 1992). The decline of these fishes during the past two decades has been attributed to overfishing, pollution, and hydrologic modification such as the construction of dams (Hightower et al. 1996, Garman et al. 1998, Sauls et al. 1998). Anadromy is the process by which marine fishes migrate to freshwater



rivers and streams to spawn. Dams constructed on major freshwater rivers often impede anadromous fishes from traveling to historical spawning habitat. Furthermore, increased mortality on accumulated and disoriented native fishes by predation from nonindigenous piscivores at dams has been documented (Raymond 1979, Reiman and Beamsderfer 1991). Intensive management programs, such as the introduction of hatchery reared larvae and the construction of fish ladders over dams, currently focus on the restoration of anadromous fishes such as American shad and blueback herring.

Anadromy may have evolved in fishes as a result of benefits such as reduced predator abundance and ideal physiochemical habitat to juvenile fishes found in the upper reaches of coastal rivers (Gross 1987, Gross et al. 1988, Roffe 1992, Limburg 1996a, Limburg 1996b). Within the tidal freshwater James River, Burbidge (1974) associated increasing numbers of juvenile *Alosa spp.* found in upper reaches of the river to greater zooplankton abundance. Conversely, other studies suggested that decreasing numbers of potential predators might be the major driving force for increased juvenile clupeid abundance in upper reaches of freshwater rivers during summer months (Limburg 1996a, Limburg 1996b). Furthermore, there is increased cover in upper reaches of freshwater rivers such as plant structures and submersed logs that facilitate predator avoidance by juvenile fishes. Anadromous clupeid fishes evolved survival strategies such as the attainment of a minimum size before fall migration to escape native, gape limited predators (Stickney 1972, Richkus 1974,

McKeown 1984, Limburg 1996b). However, *Alosa spp.*, as well as other native fishes of the James River, may not have evolved avoidance strategies to escape predation by nonindigenous blue catfish and flathead catfish which are not gape limited to all sizes of most native fishes to the James River.

An objective of this study was to describe the trophic ecology of four large catfish species that inhabit the James River, Virginia by stomach content analysis. Another objective was to evaluate the potential of these catfishes to impact native fish populations of the James River by predation. I hypothesized that blue catfish and flathead catfish may be reducing the abundance of native fish populations by predation. The effects of these nonindigenous predators may be severe, and especially to fishes such as the commercially and ecologically important anadromous alosids which have rapidly declined in recent years as a result of overfishing, habitat degradation, and the construction of dams.

## Methods

The James River is the largest river in Virginia, and is the third largest tributary of the Chesapeake Bay. It extends 531 km from the confluence of the Jackson and Cow Pasture Rivers in the Blue Ridge Mountains downstream to Hampton Roads, Virginia, where it enters into the Chesapeake Bay. The study area included the tidal freshwater reach of the James River between the fall line at Richmond to Jamestown, a distance of 110 km. This reach of the James River is similar to other tidal rivers of the Atlantic Slope with rocky and sandy substrate around the fall line at Richmond, and mostly accumulated sediments in reaches below the fall line (Garman and Neilsen, 1992). The James River is narrow and winding throughout the freshwater reaches with deep channels in narrow cuts followed by broad fluvial mud flats extending from shorelines along wider reaches. The greatest width of about 7 kilometers is just west of Hampton, Virginia. The water of the James River is fresh as far down river as Jamestown, Virginia, where salinity fluctuates between 0 and 3 ppt during normal years.

Thirteen sampling locations were chosen to represent the entire freshwater tidal James River. Catfish were also collected from the Chickahominy River, a major tributary of the James River. All thirteen locations were sampled during the summer and fall of 1996, and the spring of 1997. Sampling effort during the spring occurred between 29 April, and 19 May, 1997. This range of dates was chosen to correspond with predicted peak runs of spawning adult alosids. During the summer sampling period, catfish were collected between the

dates of 29 July and 20 August, 1996. The fall collection occurred between the dates of 10 October and 28 October, 1996. This time period was chosen to correspond with the predicted peak migration of seaward juvenile *Alosa spp.*

Catfish samples were collected during all sampling dates using a 9.0 Smith-Root Generator Powered Pulsator (680 volts). Electric frequency was altered (15 to 120 pulses per second) to accommodate the capture of the four different target species. Blue catfish and flathead catfish were adequately captured using the low frequency mode (15 pulses). Because blue catfish and flathead catfish often inhabit deep pools (up to 15 m), the low frequency mode, which delivers adequate electricity to stun blue catfish and flathead catfish further through the water column than the high frequency mode (120 pulses per second), was needed to capture these two species. However, channel catfish were not captured effectively using the low frequency mode. Therefore, high frequency, or regular electrofishing was used to collect channel catfish in shallow water edges of the James River. White catfish were effectively captured using both low frequency and high frequency electrofishing.

Following capture, catfish samples were placed immediately on ice to retard digestion of prey items. The total length (mm), mass (g), sex, and sampling location were recorded for each catfish collected. Stomachs were removed from the esophagus to the pyloric sphincter, and examined visually. Stomachs not containing prey items were discarded, and stomachs containing prey were preserved in a 10% formaldehyde solution. Prey items were identified

to the lowest possible taxon using a dissecting microscope (25x), and then enumerated. When prey items such as detritus and plant remains could not be counted, occurrence of these prey items in a single stomach was given the value of 1, as suggested by Hyslop (1980). Fish prey were examined visually to determine if accuracy of measured weight would be compromised by previous digestion. If accurate estimates of the actual prey weight before ingestion could not be obtained as a result of substantially depleted biomass, then estimated prey weight was reconstructed with a regression of pooled prey lengths and weights for fish prey ( $r^2 = 0.93$ ). A library of scales from potential prey fishes was created from samples collected from the James River to serve as a visual comparative tool for the identification of unidentified fish prey by scale characteristics as suggested by Garman (1982). Scales from different sizes of potential fish prey were mounted on glass slides for comparison with recovered scales of fish prey taken from catfish stomachs.

An attempt was made to collect catfish samples in numbers representative of the actual relative abundance of the 4 species in the James River. However, actual relative abundance cannot be assumed in this sample due to electrofishing gear bias, as low frequency electrofishing was extremely effective for collecting flathead catfish and blue catfish, moderately effective in white catfish collection, and ineffective for collecting channel catfish.

For purpose of analysis, spatial patterns were not recognized as an important variable to explain differences of catfish diets within and between

species. Therefore only putative predator size, species, and sampling seasons were compared. Sampling dates were divided into seasonal components (spring, summer, and fall). Broad size comparisons were divided among suggested lengths at maturity for the four target species: channel catfish (juvenile < 350 mm TL), flathead catfish (juvenile < 450 mm TL), and blue catfish (juvenile < 500 mm TL) (Menzel 1945, Minckley and Deacon 1959, Carlander 1969, Pelzman 1971). More specific size comparisons were made using 100 mm size classes that encompassed the size range of each catfish species.

## Results

A total of 4,164 catfish were captured for stomach content analysis from the James River, Virginia during the summer and fall of 1996 and the spring of 1997. Blue catfish was the most numerous ictalurid collected, ( $n=2,644$ ; 63% of total catch), and flathead catfish were the least abundant of the target ictalurids sampled ( $n=156$ ; 4% of total catch). A total of 801 channel catfish and 563 white catfish were taken representing 19% and 14% of the catch. Prey remains were recovered from 2,158 catfish samples and the proportion of catfish stomachs with prey varied among species (blue catfish = 0.44, flathead catfish = 0.65, channel catfish = 0.66, and white catfish = 0.42), and averaged 0.54 for all four species combined.

The size range and the maximum length of blue catfish (53-1190 mm TL) and flathead catfish (67-951 mm TL) were considerably larger than the length range and maximum size of channel catfish (60-642 mm TL) and white catfish (58-468 mm TL) (Fig. 1). The length frequency distributions of channel catfish and white catfish were approximately normal, with the majority of samples occurring in mid-size classes. The length frequency distribution for blue catfish was skewed towards smaller size classes, with most fish ranging between 200 mm and 400 mm. In contrast, the length frequency distribution of flathead catfish was relatively even throughout the range of length classes. (Fig. 1).

The diets of the four ictalurids differed among species as well as among sampling seasons (Fig. 2). Fish prey were more important in the diets of large blue catfish (> 500 mm) and large flathead catfish (>450 mm) (> 0.75 frequency of occurrence during all seasons) (Tables 1 - 5), than in the diets of large channel catfish (>350 mm) and white catfish (< 0.14 frequency of occurrence during all seasons) (Tables 6 - 11). Flathead catfish were the most piscivorous of the four catfish species examined and shifted to a mostly piscivorous diet at predator lengths > 200 mm (Tables 4 - 5; Fig. 2 - 3). Blue catfish > 400 mm consumed mostly invertebrate prey (0.8 - 1.0 frequency of occurrence) (Fig. 3) such as insects and mollusks, as well as fish eggs, detritus, and plant material, and began shifting to a diet of mostly fish at lengths of 400 - 500 mm (Fig. 3; Tables 1, 2, and 3).

Channel catfish and white catfish exhibited similar omnivorous feeding habits during the three sampling seasons (Fig. 2). However, the frequency of occurrence of plant material was much greater in both large and small channel catfish collected in the fall (small = 0.38 , large = 0.76 frequency of occurrence) than white catfish collected in the fall (0.31 frequency of occurrence) (Tables 7 and 10).

The dominant families of fish prey consumed by blue catfish and flathead catfish were Clupeidae, Cyprinidae, Ictaluridae, and Moronidae (Fig. 4). Moronidae was the dominant fish taxa consumed by both predator species



across all three sampling seasons (Fig. 4). However, *Alosa spp.* (0.27 numerical proportion) was the dominant fish prey taxa consumed by blue catfish in the fall (Table 12). The mean number of 4 out of 7 major fish taxa found in flathead catfish stomachs examined was significantly greater ( $p < 0.05$ ) than that found in stomachs of blue catfish collected from the James River (Fig. 5). Although the numerical frequency of moronids consumed by flathead catfish was greater than any other fish prey category during all seasons, the gravimetric proportion of ictalurids (0.86) far exceeded the gravimetric proportion of moronids (0.11) in the summer and fall seasons (Table 13). During the spring sampling season, the gravimetric proportion of *Dorosoma cepedianum* (0.52) consumed by flathead catfish exceeded the gravimetric proportion of moronid fish prey (0.30) (Table 13).

The mean length of fish prey consumed by flathead catfish was larger than the mean fish prey length consumed by blue catfish in all predator size classes ( $p < 0.05$ ) except 500-599 mm T.L. (Fig. 6). Also, the mean number of fish prey consumed by flathead catfish was significantly greater ( $p < 0.05$ ) than blue catfish in all predator size classes excluding 600-700 mm (Fig. 7). Blue catfish fed on juvenile ( $\leq 100$  mm) *Alosa spp.* in the summer and fall (Fig. 8). In contrast, flathead catfish did not consume juvenile *Alosa spp.* in the summer and fall seasons (Table 13; Fig. 9), but during the spring season, the consumption of *Alosa spp.* prey by both blue catfish and flathead catfish was limited to adults ( $>150$  mm S.L.) (Table 13; Fig. 8 and 9). Small blue catfish predators ( $<500$  mm

T.L.) consumed more *Alosa spp.* during the summer and fall seasons (Fig. 10) than for larger blue catfish predators (> 500 mm T.L.) in the spring season (Fig. 11). Although channel catfish and white catfish consumed fish prey in larger size classes (Tables 14 -15; Fig. 3), the frequency of occurrence of fish prey in all blue catfish (0.31) and flathead catfish (0.94) examined was greater than the occurrence of fish prey in channel catfish (0.06) and white catfish (0.04).

## Discussion

Both blue catfish and flathead catfish in the James River reached comparable sizes and exhibited piscivory. However, small blue catfish (< 400 mm T.L.) in this study were mostly omnivorous, in contrast to small flathead catfish which became piscivorous in predator sizes > 250 mm. Flathead catfish also became piscivorous around 250 mm in Alabama and Kansas rivers (Minckley and Deacon 1959, Brown and Dendy 1961). Blue catfish in Alabama were more omnivorous than flathead catfish at smaller predator sizes, but shifted to more extensive fish consumption at larger predator sizes (Brown and Dendy 1961). This trend was observed in James River blue catfish as adults (> 500 mm) which gradually shifted to nearly exclusive fish diets with increasing predator length.

Flathead catfish in Oklahoma reservoirs consumed over 95% fish prey (Turner and Summerfelt 1970). Introduced flathead catfish in the Cape Fear River, North Carolina consumed 99.4 % (by weight) fish prey (Guier et al. 1984). In the James River, flathead catfish consumed over 90 % (frequency of occurrence) fish prey. Although the occurrence of fish prey in flathead catfish was similar across sampling locations, many diet studies have reported differing prey species across rivers and reservoirs consumed by both blue catfish and flathead catfish (Minckley and Deacon 1959, Brown and Dendy 1961, Turner and Summerfelt 1970, Guier et al. 1984). The change in fish taxa consumed by predators such as blue catfish and flathead catfish could have been shaped by

changes in relative prey abundance in different rivers (Minckley and Deacon 1959, Langemeier 1965, Scott and Murdoch, 1983).

Flathead catfish consumed larger fish prey than blue catfish in most predator size classes. One explanation for difference in the size of fish prey consumed may be the contrasting morphological attributes of the two predator species such as gape length. Other studies (Scott and Murdoch 1983, Schmidt and Holbrook 1984) suggested in support of this hypothesis that gape limitation in a predator may be a causal variable in predator size selectivity. Flathead catfish grew faster than blue catfish in the James River (M.A. King, unpublished data). Faster growth rates in flathead catfish might be attributed to the ability of flathead catfish to consume more, and larger fish prey at earlier ages. These findings suggest that introduced flathead catfish may reduce greater numbers of native fishes by predation than blue catfish as novel apex predators in Atlantic slope coastal rivers. However, the relative abundance of blue catfish to flathead catfish in the 1996 - 1997 James River sample was about 16:1. The more abundant blue catfish may be reducing numbers of native fishes by predation at a greater rate than flathead catfish.

Channel catfish are considered opportunistic omnivores and feed on a wide variety of prey types in mid-western rivers (Bailey and Harrison 1948, Russel 1965). Channel catfish diet studies suggest that invertebrates are the principal food item in reservoirs of Florida and Oklahoma (Clemens 1952, Ware 1966). Sule et al. (1981) documented a shift in channel catfish to a diet of mostly

fish and decapods at predator lengths > 500 mm in Illinois, while channel catfish in Nebraska rivers began consuming fish prey around 250 mm (Zuerlein 1982). Consumption of fish prey by channel catfish in the James River began at predator lengths between 300 mm and 400 mm. This study demonstrated that larger prey items such as fish and decapods consumed by channel catfish become increasingly important with increasing predator length. However, the occurrence of invertebrate prey consumed by channel catfish remained dominant in larger predator sizes in the James River, suggesting that channel catfish are omnivorous throughout the predator size range. White catfish have also been considered omnivorous (Menzel 1945, Carlander 1969). However, relatively few diet studies have included this native ictalurid to the James River that exhibited similar omnivorous feeding behavior to channel catfish in this study.

No other studies have concluded that ictalurids are physiologically able to utilize plant material as a source of food energy, although diet studies in Colorado, Illinois, and Virginia reported substantial amounts of plant material in ictalurid diets (McCormick 1940, Dill 1944, Menzel 1945, Sule et al. 1981). The James River data revealed plant material as a large component of white catfish and channel catfish stomach contents during the spring and fall sampling seasons. This plant material may have been ingested incidentally by channel catfish and white catfish while consuming benthic invertebrates. However, these data support the hypothesis that plant material may be an important energetic component of catfish diets, at least on a seasonal basis, and especially of

channel catfish, which consumed over 76 % (frequency of occurrence) plant matter during the fall sampling period.

This study demonstrated that large blue catfish and flathead catfish are able to consume most size classes of native fishes found in the tidal freshwater James River. However, most blue catfish taken in this study were < 500 mm T.L. Although small blue catfish are gape limited to larger fish prey such as adult *Alosa spp.*, juvenile blue catfish began consuming substantial numbers of smaller fish prey at predator lengths < 300 mm in the James River. A large proportion of fish prey consumed by small blue catfish (< 500) during the summer and fall sampling seasons were age-0 *Alosa spp.* Fish prey occurred more than any other prey item in the fall diets of juvenile blue catfish of the James River, although invertebrate prey items were dominant in the spring and summer. This suggests feeding flexibility in juvenile blue catfish that were not gape limited to feeding on migrating age-0 *Alosa spp.* in the fall, and shifted to more abundant invertebrate prey during other seasons. Similar feeding flexibility was also observed in the piscivorous northern pike (*Esox lucius*) that shifted seasonally from consuming mostly fish to more abundant invertebrate prey (Chapman, 1989).

Freshwater aquatic ecosystems such as Atlantic slope tidal rivers have few native piscivores. It has been suggested that the maximum attainable biomass of these freshwater rivers has historically been controlled through a bottom-up trophic cascade (McQueen et al. 1986, McQueen et al. 1989). The

effects of introduced apex predators in freshwater ecosystems are poorly understood (Taylor et al. 1984, Sauls et al. 1998). However, nonindigenous piscivores, such as blue catfish and flathead catfish, could impose top-down effects that could potentially alter an entire freshwater ecosystem (Carpenter and Kitchell 1988, Bechara et al. 1992).

Anadromy may have evolved in fishes such as *Alosa spp.* as a result of increased reproductive fitness associated with reduced predator abundance and ideal physiochemical habitat to juvenile fishes found in the upper reaches of coastal rivers (Gross 1987, Gross et al. 1988, Roffe 1992, Limburg 1996a, Limburg 1996b). Additions of larger predators that consume all size classes of most native fish species may reduce the benefits of anadromy for native fishes. Both blue catfish and flathead catfish consumed adult *Alosa spp.* during spring spawning migrations in the James River, and there was also substantial predation on out-migrating age-0 herring by blue catfish in the fall. The current restoration efforts to anadromous clupeid fishes may be compromised in Atlantic slope coastal rivers as a consequence of nonindigenous blue catfish and flathead catfish introductions.

Although most fish introductions may not be detrimental to native taxa, the decline of native fishes associated with introduced piscivores is well documented (Hocutt 1984, Moyle and Light 1996). The ecological impact of introduced ictalurids in Atlantic Slope coastal rivers cannot be quantified by this study. However, I have demonstrated that nonindigenous blue catfish and flathead

catfish in the James River have characteristics of other introduced piscivores that have been associated with the decline, or even extirpation of native fishes in other aquatic ecosystems.



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Table 1. Occurrence of prey items from two size categories of blue catfish, (*Ictalurus furcatus*) stomachs collected from 13 locations on the freshwater tidal James River during the summer of 1996. Importance is expressed as frequency of occurrence, (numerical proportion in parenthesis).

Prey Category	< 500 mm TL (n=351)	500 - 1190 mm TL (n=36)
Aquatic Insects	0.54 (0.39)	0.06 (0.25)
Terrestrial Insects	<0.01 (0.01)	0.00 (0.00)
Decapods	0.03 (<0.01)	0.19 (0.10)
Other Crustaceans	0.30 (0.45)	0.00 (0.00)
Gastropods	0.01 (<0.01)	0.03 (0.01)
Bivalves	0.19 (0.11)	0.00 (0.00)
Fish	0.24 (0.03)	0.83 (0.64)
Fish Eggs	0.00 (N/A)	0.00 (N/A)
Plant Material	0.12 (N/A)	0.03 (N/A)
Detritus	0.06 (N/A)	0.00 (N/A)
Miscellaneous	0.28 (N/A)	0.14 (N/A)
	(0.98)	(1.00)

<sup>a</sup> N/A = not applicable

Table 2. Occurrence of prey items from two size categories of blue catfish, (*Ictalurus furcatus*) stomachs collected from 13 locations on the freshwater tidal James River during the fall of 1996. Importance is expressed as frequency of occurrence, (numerical proportion in parenthesis).

Prey Category	< 500 mm TL (n=351)	500 - 1190 mm TL (n=36)
Aquatic Insects	0.16 (0.29)	0.02 (0.02)
Terrestrial Insects	<0.01 (<0.01)	0.00 (0.00)
Decapods	0.11 (0.08)	0.03 (0.07)
Other Crustaceans	0.14 (0.26)	0.02 (0.03)
Gastropods	<0.01 (<0.01)	0.00 (0.00)
Bivalves	0.09 (0.12)	0.02 (0.02)
Fish	0.36 (0.25)	0.70 (0.87)
Fish Eggs	<0.01 (N/A)	0.00 (N/A)
Plant Material	0.31 (N/A)	0.33 (N/A)
Detritus	0.11 (N/A)	0.02 (N/A)
Miscellaneous	0.11 (N/A)	0.12 (N/A)
	(1.00)	(0.94)

<sup>a</sup> N/A = not applicable

Table 3. Occurrence of prey items from two size categories of blue catfish, (*Ictalurus furcatus*) stomachs collected from 13 locations on the freshwater tidal James River during the spring of 1997. Importance is expressed as frequency of occurrence, (numerical proportion in parenthesis).

Prey Category	< 500 mm TL (n=351)	500 - 1190 mm TL (n=36)
Aquatic Insects	0.35 (0.32)	0.03 (0.19)
Terrestrial Insects	<0.01 (0.00)	0.00 (0.00)
Decapods	0.01 (<0.01)	0.01 (<0.01)
Other Crustaceans	0.36 (0.34)	0.00 (0.00)
Gastropods	0.01 (<0.01)	0.01 (<0.01)
Bivalves	0.29 (0.32)	0.02 (0.04)
Fish	0.15 (0.02)	0.90 (0.75)
Fish Eggs	0.28 (N/A)	0.02 (N/A)
Plant Material	0.26 (N/A)	0.06 (N/A)
Detritus	0.41 (N/A)	0.04 (N/A)
Miscellaneous	0.19 (N/A)	0.07 (N/A)
	(0.98)	(0.98)

<sup>a</sup> N/A = not applicable

Table 4. Occurrence of prey items from two size categories of flathead catfish, (*Pylodictus olivaris*) stomachs collected from 13 locations on the freshwater tidal James River during the summer and fall of 1996. Importance is expressed as frequency of occurrence, (numerical proportion in parenthesis).

Prey Category	< 450 mm TL (n=14)	450 - 951 mm TL (n=10)
Aquatic Insects	0.16 (0.13)	0.10 (0.08)
Terrestrial Insects	0.00 (0.00)	0.00 (0.00)
Decapods	0.08 (0.03)	0.00 (0.00)
Other Crustaceans	0.08 (0.13)	0.10 (0.12)
Gastropods	0.00 (0.00)	0.00 (0.00)
Bivalves	0.00 (0.00)	0.00 (0.00)
Fish	0.77 (0.70)	1.00 (0.81)
Fish Eggs	0.00 (N/A)	0.00 (N/A)
Plant Material	0.00 (N/A)	0.00 (N/A)
Detritus	0.00 (N/A)	0.00 (N/A)
Miscellaneous	0.08 (N/A)	0.00 (N/A)
	(0.99)	(1.01)

<sup>a</sup> N/A = not applicable

Table 5. Occurrence of prey items from two size categories of flathead catfish, (*Pylodictus olivaris*) stomachs collected from 13 locations on the freshwater tidal James River during the spring of 1997. Importance is expressed as frequency of occurrence, (numerical proportion in parenthesis).

Prey Category	< 450 mm TL (n=24)	450 - 951 mm TL (n=56)
Aquatic Insects	0.04 (0.03)	0.02 (<0.01)
Terrestrial Insects	0.00 (0.00)	0.00 (0.00)
Decapods	0.00 (0.00)	0.00 (0.00)
Other Crustaceans	0.08 (0.31)	0.00 (0.00)
Gastropods	0.00 (0.00)	0.00 (0.00)
Bivalves	0.04 (0.26)	0.00 (0.00)
Fish	0.88 (0.39)	0.98 (0.99)
Fish Eggs	0.00 (N/A)	0.00 (N/A)
Plant Material	0.04 (N/A)	0.00 (N/A)
Detritus	0.04 (N/A)	0.00 (N/A)
Miscellaneous	0.00 (N/A)	0.06 (N/A)

<sup>a</sup> N/A = not applicable



Table 6. Occurrence of prey items from two size categories of channel catfish, (*Ictalurus punctatus*) stomachs collected from 13 locations on the freshwater tidal James River during the summer of 1996. Importance is expressed as frequency of occurrence, (numerical proportion in parenthesis).

Prey Category	< 350 mm TL (n=155)	350-642 mm TL (n=66)
Aquatic Insects	0.91 (0.74)	0.70 (0.99)
Terrestrial Insects	0.05 (<0.01)	0.05 (<0.01)
Decapods	<0.01 (0.00)	0.09 (<0.01)
Other Crustaceans	0.29 (0.25)	0.06 (<0.01)
Gastropods	0.00 (0.00)	0.00 (0.00)
Bivalves	0.04 (<0.01)	0.04 (<0.01)
Fish	0.02 (<0.01)	0.11 (<0.01)
Fish Eggs	<0.01 (N/A)	0.00 (N/A)
Plant Material	0.25 (N/A)	0.23 (N/A)
Detritus	0.18 (N/A)	0.23 (N/A)
Miscellaneous	0.15 (N/A)	0.26 (N/A)
	(0.99)	(0.99)

<sup>a</sup> N/A = not applicable

Table 7. Occurrence of prey items from two size categories of channel catfish, (*Ictalurus punctatus*) stomachs collected from 13 locations on the freshwater tidal James River during the fall of 1996. Importance is expressed as frequency of occurrence, (numerical proportion in parenthesis).

Prey Category	< 350 mm TL (n=59)	350-642 mm TL (n=101)
Aquatic Insects	0.52 (0.55)	0.32 (0.73)
Terrestrial Insects	0.07 (0.01)	0.11 (0.23)
Decapods	0.21 (0.04)	0.17 (0.02)
Other Crustaceans	0.12 (0.40)	0.02 (<0.01)
Gastropods	0.00 (0.00)	0.00 (0.00)
Bivalves	0.02 (<0.01)	0.02 (<0.01)
Fish	0.02 (<0.01)	0.05 (<0.01)
Fish Eggs	0.00 (N/A)	0.00 (N/A)
Plant Material	0.38 (N/A)	0.76 (N/A)
Detritus	0.07 (N/A)	0.07 (N/A)
Miscellaneous	0.17 (N/A)	0.19 (N/A)
	(1.00)	(0.98)

<sup>a</sup> N/A = not applicable

Table 8. Occurrence of prey items from two size categories of channel catfish, (*Ictalurus punctatus*) stomachs collected from 13 locations on the freshwater tidal James River during the spring of 1997. Importance is expressed as frequency of occurrence, (numerical proportion in parenthesis).

Prey Category	< 350 mm TL (n=47)	350-642 mm TL (n=112)
Aquatic Insects	0.70 (0.47)	0.54 (0.61)
Terrestrial Insects	0.00 (0.00)	<0.01 (<0.01)
Decapods	0.02 (<0.01)	0.04 (0.01)
Other Crustaceans	0.26 (0.36)	0.14 (0.26)
Gastropods	0.02 (<0.01)	0.00 (0.00)
Bivalves	0.13 (0.16)	0.04 (0.07)
Fish	0.02 (<0.01)	0.14 (0.05)
Fish Eggs	0.40 (N/A)	0.29 (N/A)
Plant Material	0.40 (N/A)	0.39 (N/A)
Detritus	0.72 (N/A)	0.52 (N/A)
Miscellaneous	0.30 (N/A)	0.41 (N/A)
	(0.99)	(0.99)

<sup>a</sup> N/A = not applicable

Table 9. Occurrence of prey items from white catfish, (*Ameiurus catus*)

stomachs collected from 13 locations on the freshwater tidal James River during the summer of 1996. Importance is expressed as frequency of occurrence, (numerical proportion in parenthesis).

Prey Category	(n=118)
Aquatic Insects	0.92 (0.87)
Terrestrial Insects	0.00 (0.00)
Decapods	0.00 (0.00)
Other Crustaceans	0.23 (0.12)
Gastropods	<0.01 (<0.01)
Bivalves	0.03 (<0.01)
Fish	0.02 (<0.01)
Fish Eggs	0.00 (N/A)
Plant Material	0.19 (N/A)
Detritus	0.05 (N/A)
Miscellaneous	0.08 (N/A)
	(0.99)

<sup>a</sup> N/A = not applicable

Table 10. Occurrence of prey items from white catfish, (*Ameiurus catus*) stomachs collected from 13 locations on the freshwater tidal James River during the fall of 1996. Importance is expressed as frequency of occurrence, (numerical proportion in parenthesis).

Prey Category	(n=53)
Aquatic Insects	0.33 (0.44)
Terrestrial Insects	0.02 (<0.01)
Decapods	0.16 (0.10)
Other Crustaceans	0.22 (0.34)
Gastropods	0.02 (0.06)
Bivalves	0.02 (<0.01)
Fish	0.06 (0.04)
Fish Eggs	0.02 (N/A)
Plant Material	0.31 (N/A)
Detritus	0.33 (N/A)
Miscellaneous	0.14 (N/A)
	(0.98)

<sup>a</sup> N/A = not applicable

Table 11. Occurrence of prey items from white catfish, (*Ameiurus catus*) stomachs collected from 13 locations on the freshwater tidal James River during the spring of 1997. Importance is expressed as frequency of occurrence, (numerical proportion in parenthesis).

Prey Category	(n=53)
Aquatic Insects	0.44 (0.47)
Terrestrial Insects	0.03 (0.06)
Decapods	0.01 (<0.01)
Other Crustaceans	0.24 (0.40)
Gastropods	0.00 (0.00)
Bivalves	0.04 (0.03)
Fish	0.05 (0.04)
Fish Eggs	0.51 (N/A)
Plant Material	0.54 (N/A)
Detritus	0.72 (N/A)
Miscellaneous	0.17 (N/A)
	(1.00)

<sup>a</sup> N/A = not applicable

Table 12. Occurrence of fish prey from blue catfish collected from 13 locations on the freshwater tidal James River during three seasons. Importance is expressed as frequency of occurrence (F), numerical proportion (P), and gravimetric proportion (G).

Prey Category	Summer, 1996			Fall, 1996			Spring, 1997		
	(n=104)			(n=93)			(n=162)		
	F	N	G	F	N	G	F	N	G
<b>Clupeidae</b>									
<i>Alosa spp.</i>	0.07	0.09	0.02	0.17	0.27	0.06	0.05	0.05	0.09
<i>Dorosoma sp.</i>	0.07	0.06	0.68	0.11	0.09	0.52	0.12	0.12	0.60
Unidentifiable	0.02	0.01	N/C	0.02	0.01	0.01	0.02	0.02	N/C
Cyprinidae	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.14	0.02
Ictaluridae	0.06	0.06	0.11	0.04	0.03	0.30	0.02	0.02	0.09
<b>Moronidae</b>									
<i>Morone sp.</i>	0.28	0.30	0.17	0.07	0.07	0.08	0.17	0.19	0.18
<b>Anguillidae</b>									
<i>Anguilla sp.</i>	0.00	0.00	0.00	0.05	0.04	0.01	0.04	0.03	0.02
Unidentifiable	0.48	0.42	0.01	0.53	0.49	0.03	0.48	0.44	0.00
Other Fish	0.02	0.05	0.01	0.01	<0.01	N/C	0.00	0.00	0.00
	0.99	1.00		1.00	1.01		1.01	1.00	

<sup>a</sup> n = number of stomachs containing fish

<sup>b</sup> N/C = not calculated

Table 13. Occurrence of fish prey from flathead catfish collected from 13

locations on the freshwater tidal James River during three seasons.

Importance is expressed as frequency of occurrence (F) and numerical proportion (N).

Prey Category	Summer/ Fall, 1996			Spring, 1997		
	(n=20)			(n=75)		
	F	N	G	F	N	G
<b>Clupeidae</b>						
<i>Alosa spp.</i>	0.00	0.00	0.00	0.07	0.14	0.15
<i>Dorosoma cepedianum</i>	0.00	0.00	0.00	0.21	0.20	0.52
Unidentifiable	0.04	0.03	N/C	0.00	0.00	0.00
<b>Cyprinidae</b>	0.00	0.00	0.00	0.13	0.21	0.01
<b>Ictaluridae</b>	0.30	0.19	0.86	0.02	0.02	0.00
<b>Moronidae</b>						
<i>Morone americana</i>	0.26	0.41	0.11	0.43	0.35	0.30
<b>Anguillidae</b>						
<i>Anguilla rostrata</i>	0.00	0.00	0.00	0.00	0.00	0.00
Unidentifiable Fish	0.30	0.31	0.03	0.13	0.09	0.00
Other Fish	0.11	0.07	N/C	0.00	0.00	0.00
<b>Total</b>		1.01	1.00		1.01	0.98

<sup>a</sup> n = number of stomachs containing fish

<sup>b</sup> N/C = not calculated



Table 14. Occurrence of fish prey from channel catfish collected from 13

locations on the freshwater tidal James River during three seasons.

Importance is expressed as frequency of occurrence (F) and numerical proportion (N).

Prey Category	(n=33)	
	F	N
<b>Clupeidae</b>		
<i>Alosa spp.</i>	0.12	0.10
<i>Dorosoma cepedianum</i>	0.12	0.10
Unidentifiable	0.03	0.02
<b>Cyprinidae</b>	0.00	0.00
<b>Ictaluridae</b>	0.00	0.00
<b>Moronidae</b>		
<i>Morone americana</i>	0.06	0.07
<b>Anguillidae</b>		
<i>Anguilla rostrata</i>	0.00	0.00
Unidentifiable Fish	0.68	0.71
Other Fish	0.00	0.00
Total		1.00

<sup>a</sup> n = number of stomachs containing fish prey

Table 15. Occurrence of fish prey from white catfish collected from 13 locations on the freshwater tidal James River during three seasons. Importance is expressed as frequency of occurrence (F) and numerical proportion (N).

Prey Category	(n=9)	
	F	N
<b>Clupeidae</b>		
Alosa spp.	0.22	0.31
Dorosoma cepedianum	0.00	0.00
Unidentifiable	0.00	0.00
Cyprinidae	0.00	0.00
Ictaluridae	0.11	0.15
Moronidae	0.11	0.08
<b>Anguillidae</b>		
Anguilla rostrata	0.00	0.00
Unidentifiable Fish	0.56	0.46
Other Fish	0.00	0.00
Total		1.00

<sup>a</sup> n = number of stomachs containing fish prey

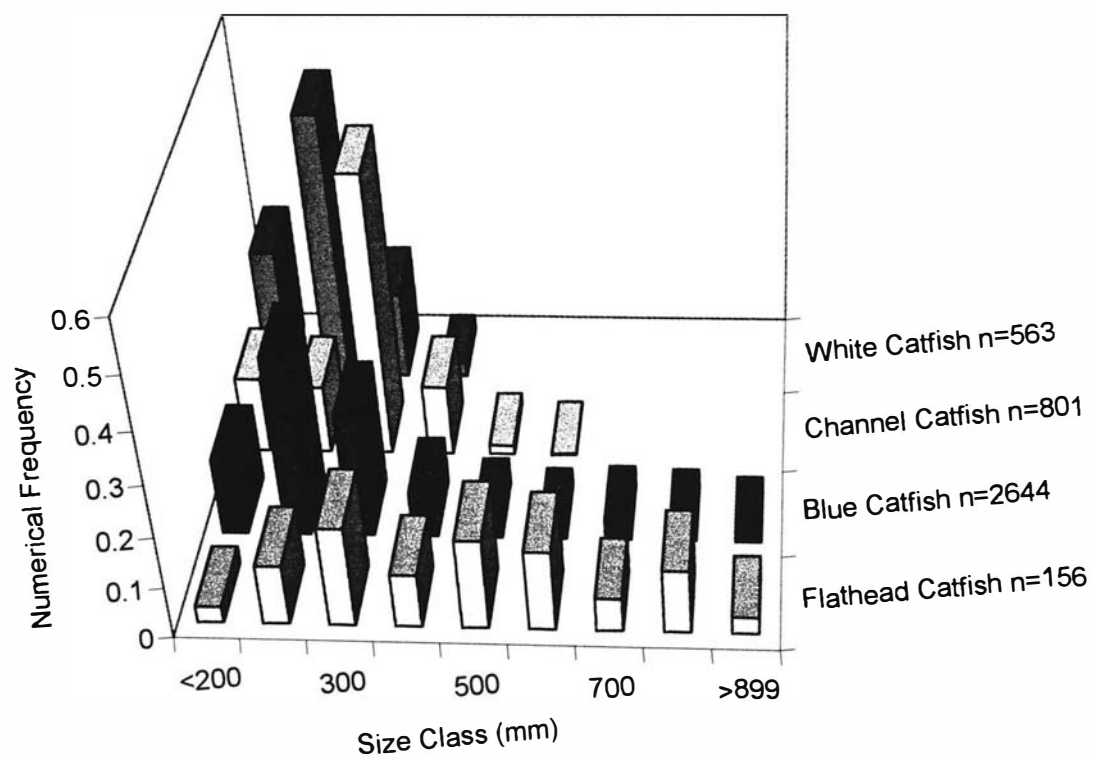
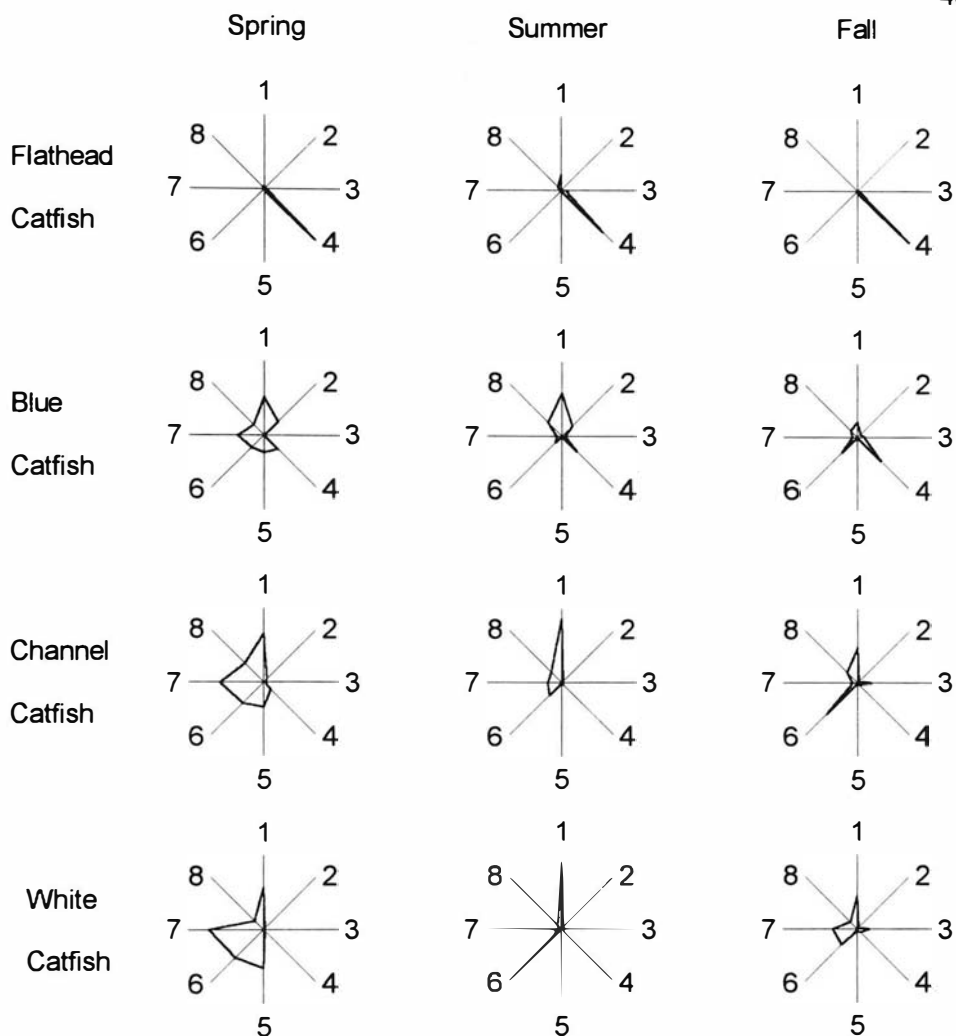


Figure 1



### Legend

1. Macroinvertebrates
2. Mollusks
3. Decapods
4. Fish
5. Fish Eggs
6. Plant Material
7. Detritus
8. Miscellaneous

**Figure 2**

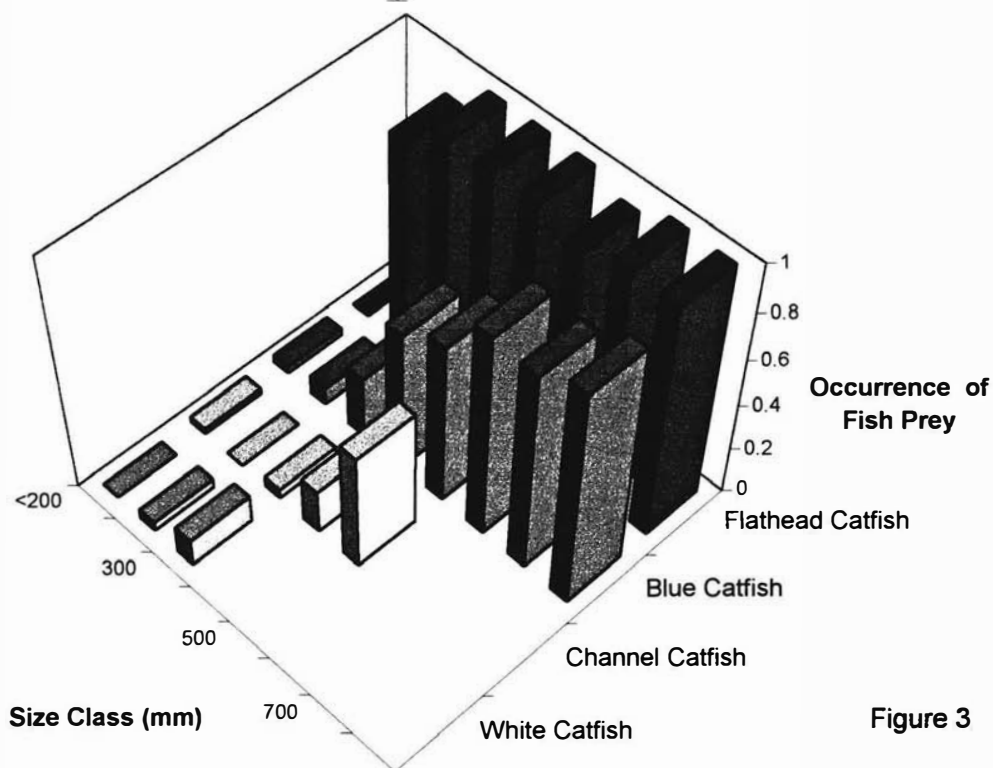
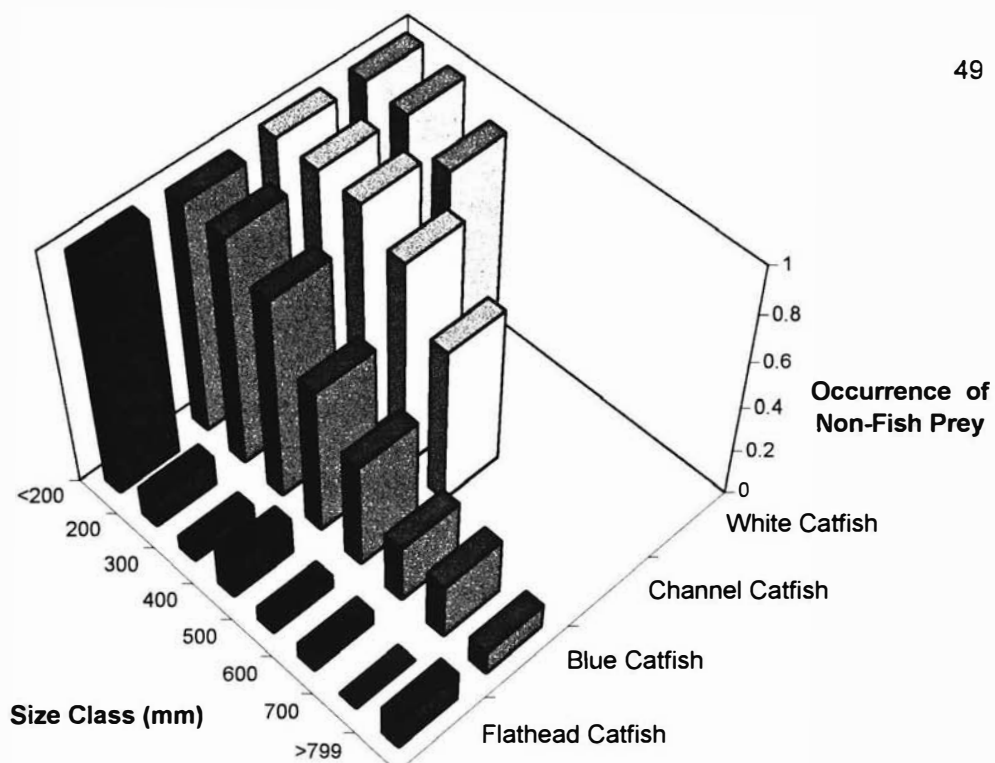


Figure 3

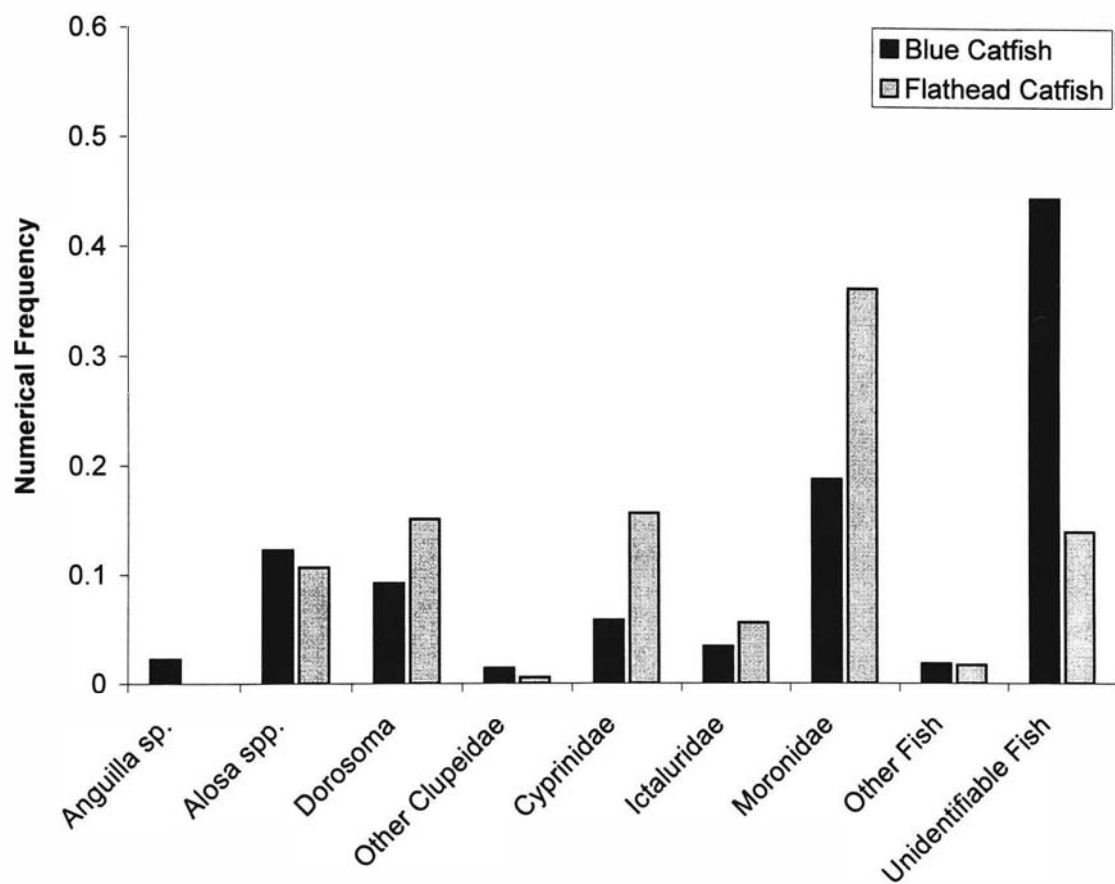


Figure 4

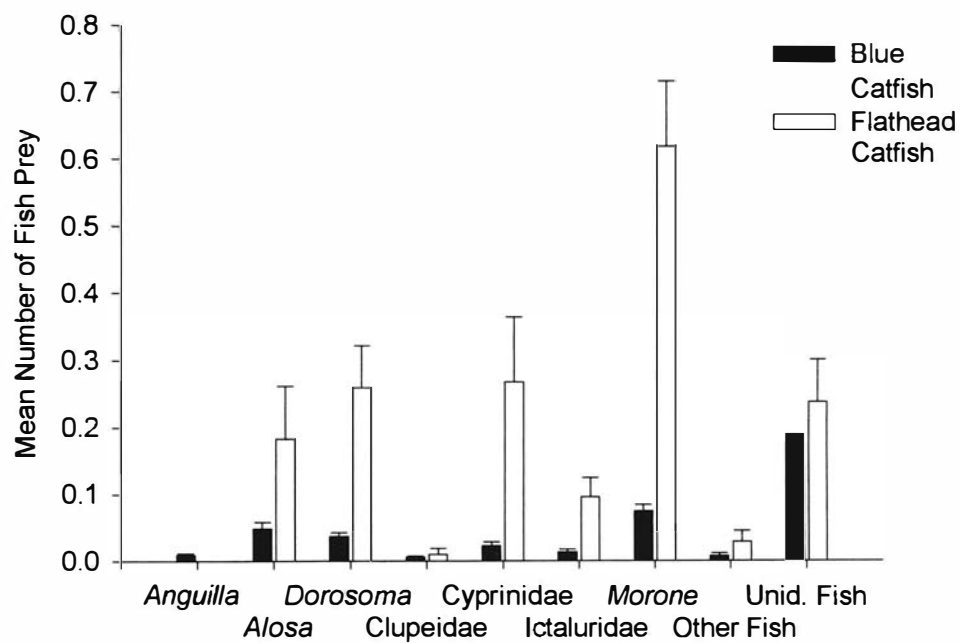


Figure 5

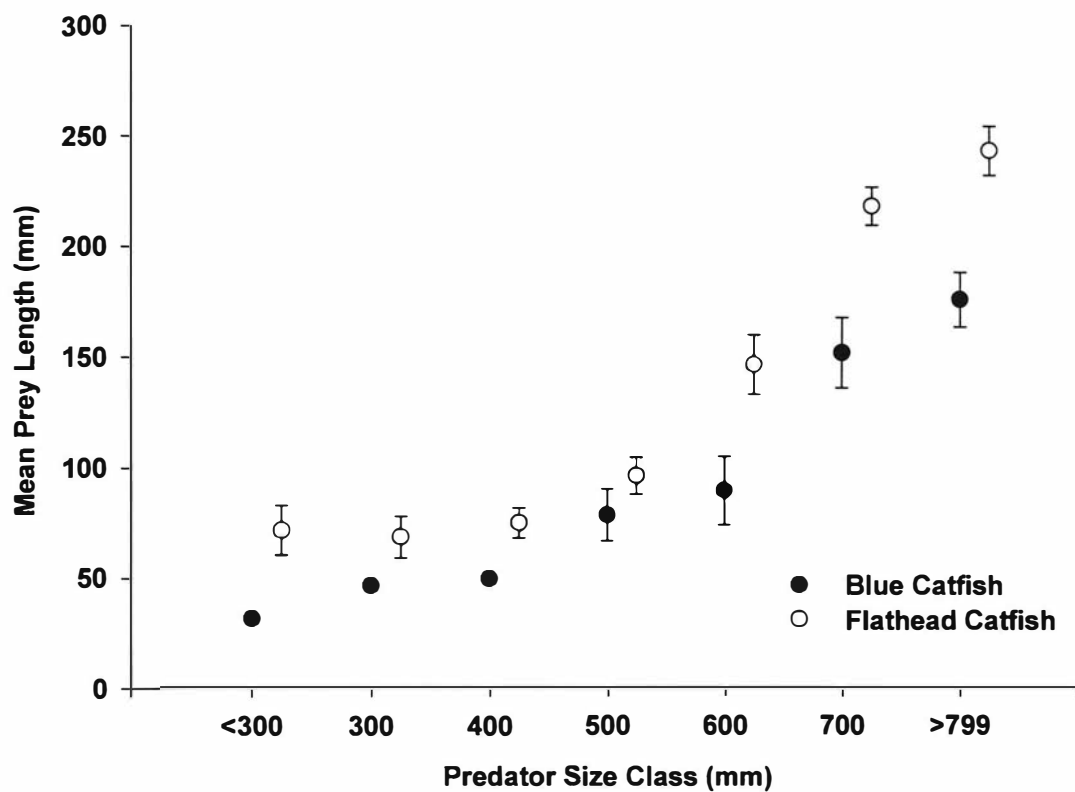


Figure 6



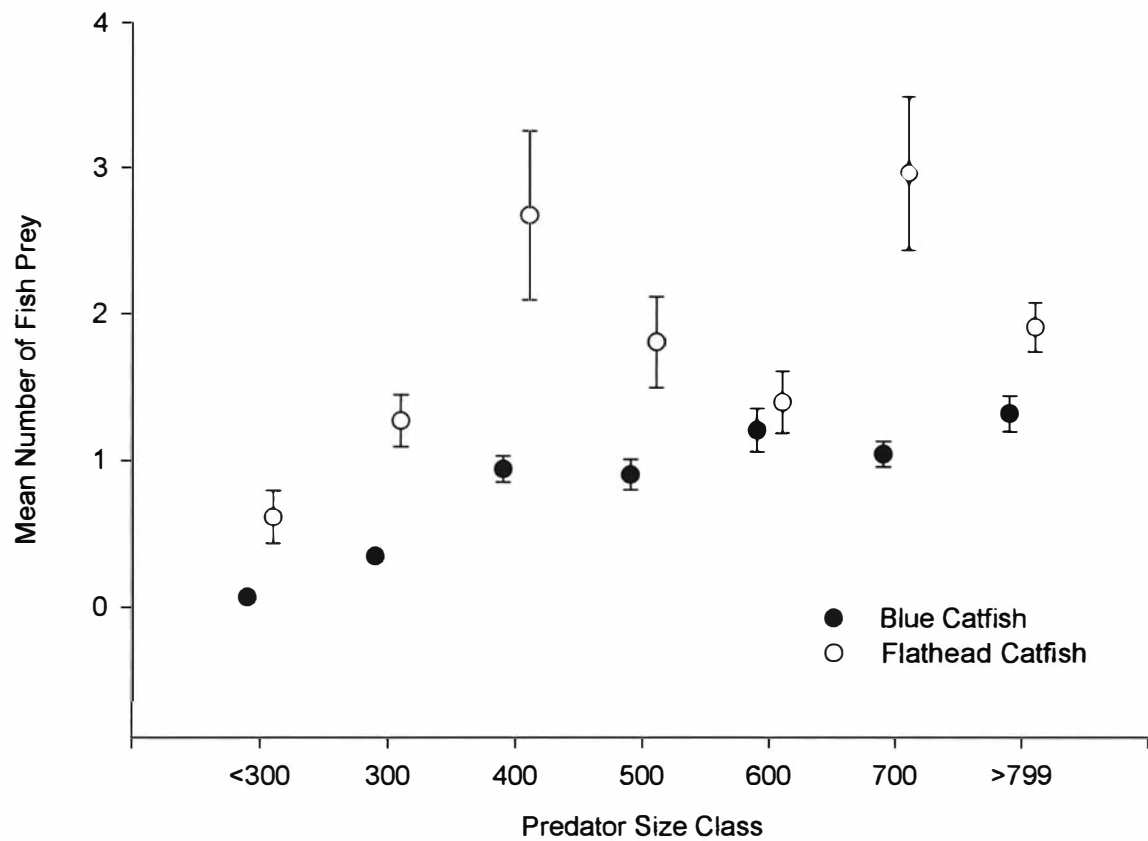


Figure 7

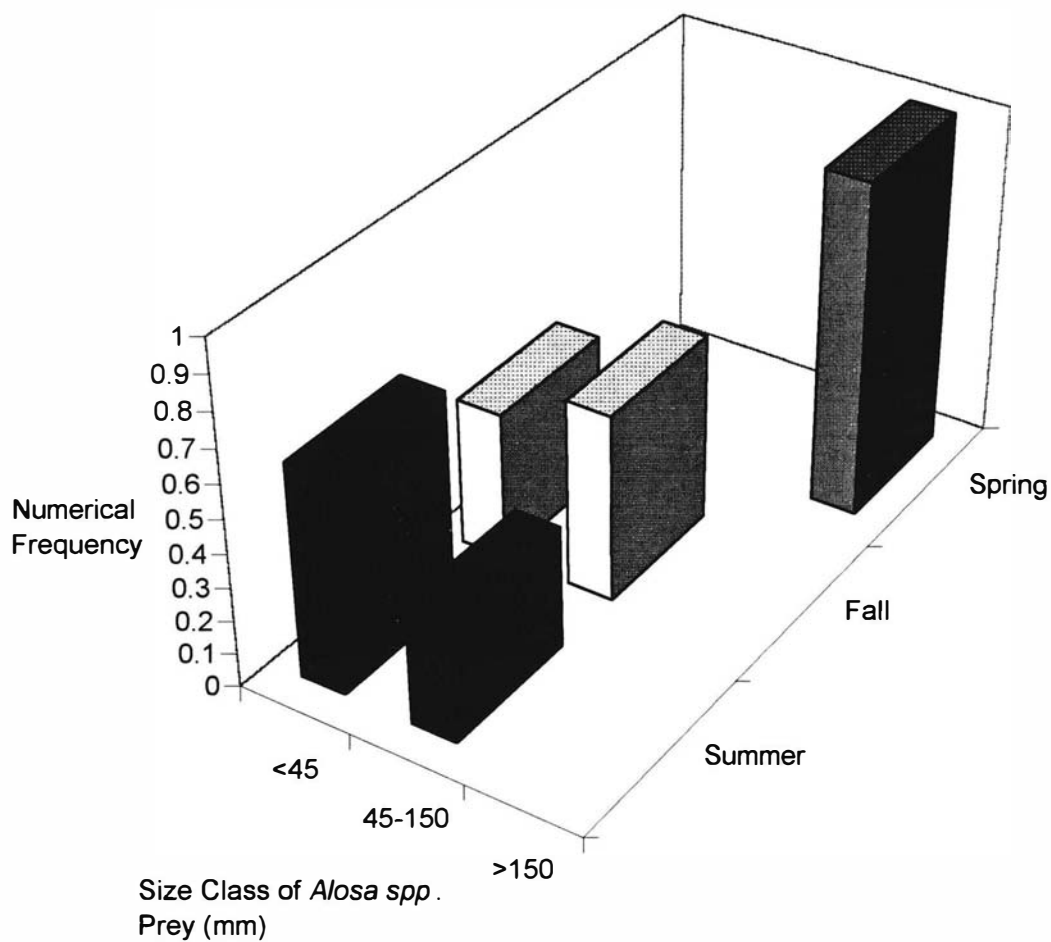


Figure 8

## Flathead Catfish

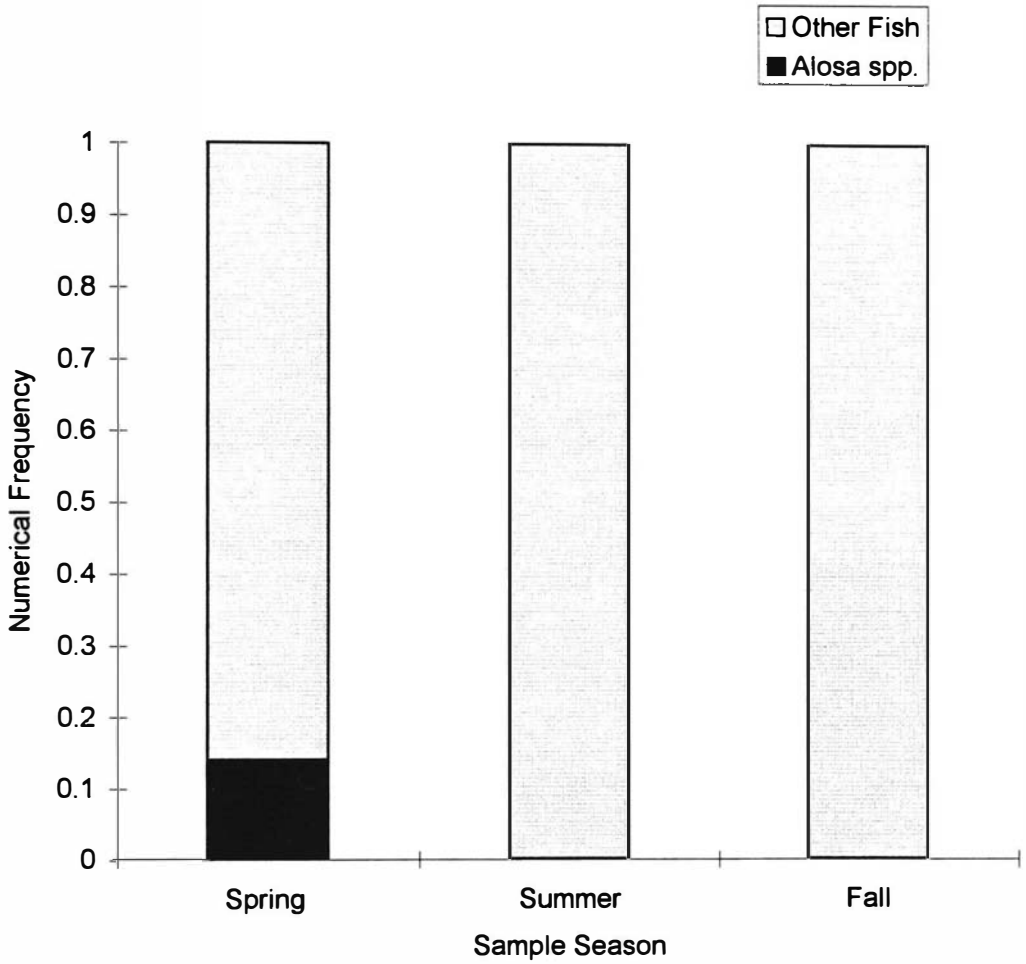


Figure 9

## Blue Catfish &lt; 500 mm

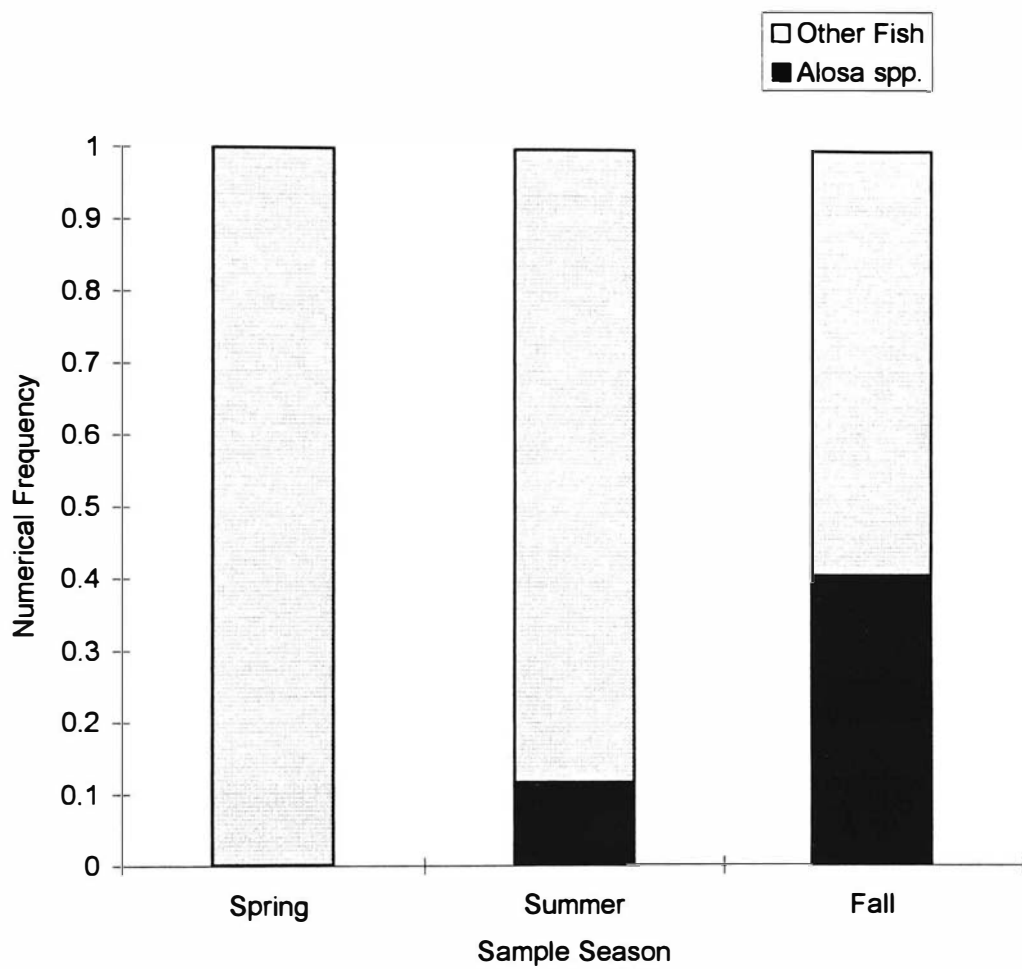


Figure 10

## Blue Catfish &gt; 500 mm

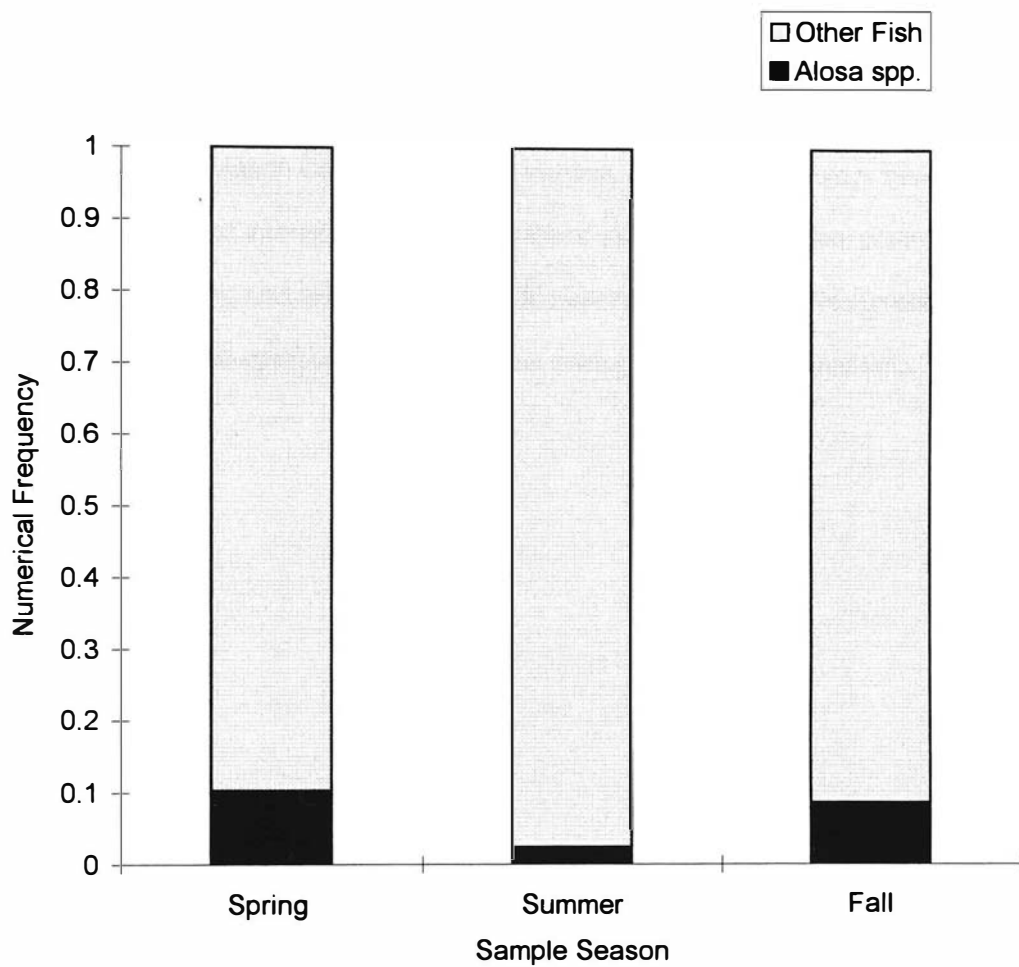


Figure 11

**Vita**